U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—1997

Open-File Report 98—653

Prepared in cooperation with the
ARIZONA DEPARTMENT OF WATER RESOURCES
and the BUREAU OF INDIAN AFFAIRS

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By G.R. LITTIN, B.M. BAUM, and M. TRUINI

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Tucson, Arizona
1999

U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS

Multiply	By	To obtain
foot (ft)	0.3048	meter
square mile (mi^2)	2.590	square kilometer
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06308	liter per second
gallon per day (gal/d)	0.003785	cubic meter per day

In this report, temperature is reported in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by using the following equation:

$$°F = 1.8(°C) + 32$$

ABBREVIATED WATER-QUALITY UNITS

Chemical concentration and water temperature are given only in metric units. Chemical concentration in water is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the solute mass (milligrams) per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million. Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

VERTICAL DATUM

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called "Sea Level Datum of 1929."

Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—1997

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Abstract

The Black Mesa monitoring program is designed to document long-term effects of ground-water pumping from the N aquifer by industrial and municipal users. The N aquifer is the major source of water in the 5,400-square-mile Black Mesa area, and the ground water occurs under confined and unconfined conditions. Monitoring activities include continuous and periodic measurements of (1) ground-water pumpage from the confined and unconfined parts of the aquifer, (2) ground-water levels in the confined and unconfined parts of the aquifer, (3) surface-water discharge, and (4) chemistry of the ground water and surface water.

In 1997, ground-water withdrawals for industrial and municipal use totaled about 7,090 acre-feet, which is less than a 1-percent increase from 1996. Pumpage from the confined part of the aquifer increased by about 2 percent to 5,510 acre-feet, and pumpage from the unconfined part of the aquifer decreased by about 4 percent to 1,580 acre-feet. Water-level declines in the confined part during 1997 were recorded in 5 of 12 wells; however, the median change was a rise of about 0.2 foot as opposed to a decline of 2.8 feet for 1996. Water-level declines in the unconfined part were recorded in 7 of 15 wells, and the median change was 0.0 foot in 1997 as opposed to a decline of 0.5 foot in 1996.

The low-flow discharge at the Moenkopi streamflow-gaging station ranged from 1.6 to 2.0 cubic feet per second in 1997. Streamflow-discharge measurements also were made at Laguna Creek, Dinnebito Wash, and Polacca Wash during 1997. The low-flow discharge ranged from 2.3 to 4.2 cubic feet per second at Laguna Creek, 0.44 to 0.48 cubic foot per second at Dinnebito Wash, and 0.15 to 0.26 cubic foot per second at Polacca Wash. Discharge was measured at three springs. Discharge from Moenkopi School Spring increased by about 3 gallons per minute from the measurement in 1996. Discharge from an unnamed spring near Dennehotso increased by 9.9 gallons per minute from the measurement made in 1996; however, discharge decreased slightly at Burro Spring. Regionally, long-term water-chemistry data for wells and springs have remained stable. Locally, water-chemistry data for some wells have shown marked increases in concentrations of major constituents.

INTRODUCTION

The N aquifer is the major source of water for industrial and municipal users in the 5,400-square-mile Black Mesa area (fig. 1) and the ground water occurs under confined and unconfined conditions. The aquifer consists of three rock formations—the Navajo Sandstone, the Kayenta Formation, and the Lukachukai Member[1] of the Wingate Sandstone—which are all of early Jurassic age (Peterson,

[1]The name Lukachukai Member was formally abandoned by Dubiel (1989) and is used herein for report continuity in the monitoring program as it relates to that part of the Wingate Sandstone included in the N aquifer.

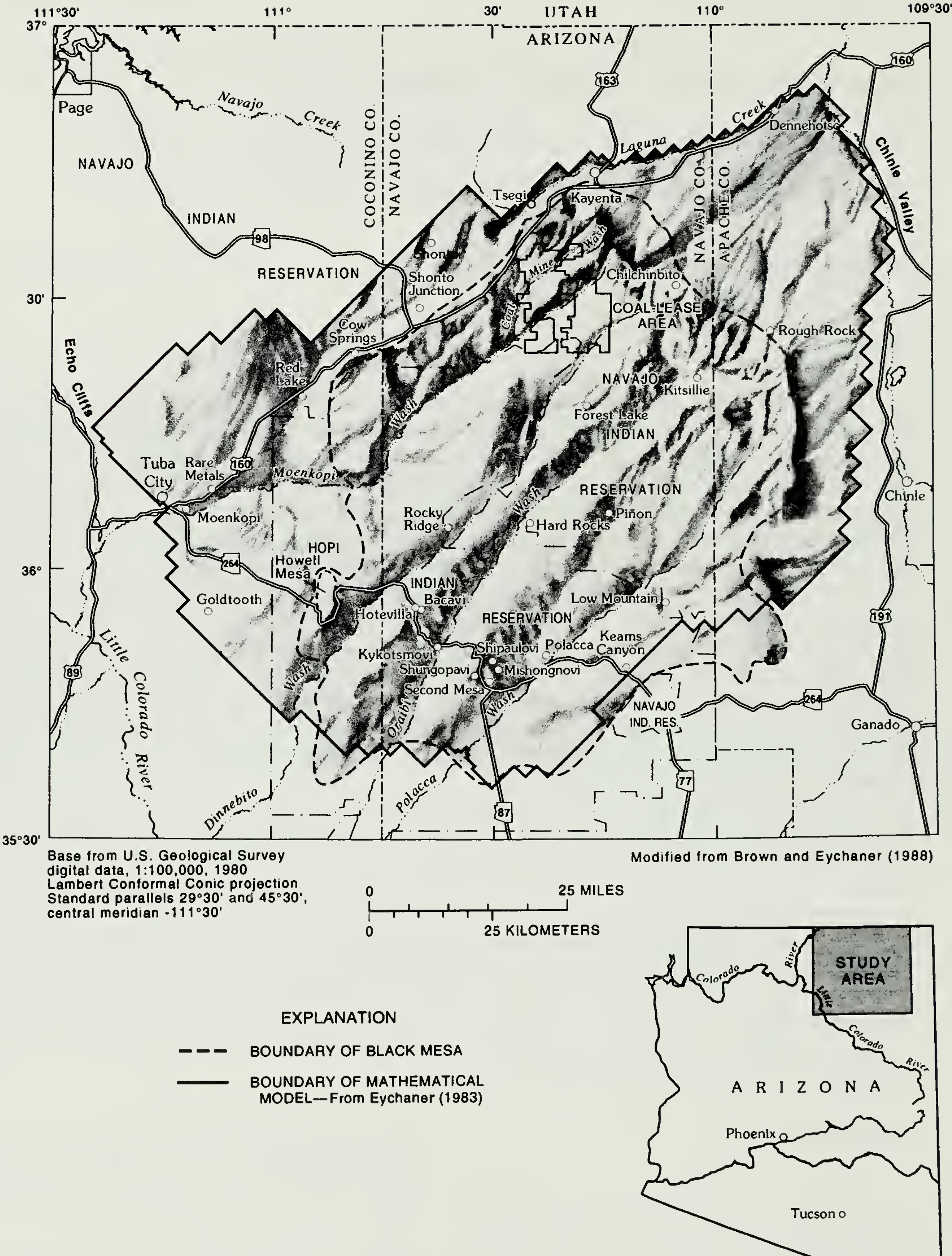


Figure 1. Location of study area.

1988). These formations are hydraulically connected and function as a single aquifer referred to as the N aquifer (fig. 2).

Total withdrawals for industrial and municipal use from the N aquifer in the Black Mesa area generally have increased during the last 29 years (table 1). Peabody Coal Company began operating a strip mine in the northern part of the mesa in 1968. The quantity of water pumped by the company increased from about 95 acre-feet (acre-ft) in 1968 to a maximum of 4,740 acre-ft in 1982. The quantity of water pumped in 1997 was 4,130 acre-ft. Withdrawals from the N aquifer for municipal use increased from an estimated 250 acre-ft in 1968 to a maximum of 4,500 acre-ft in 1991 and decreased to about 2,960 acre-ft in 1997.

The Navajo Nation and Hopi Tribe have been concerned about the long-term effects of industrial withdrawals from the N aquifer on supplies for domestic and municipal purposes. These concerns led to an investigation of the water resources of the Black Mesa area in 1971 by the U.S. Geological Survey (USGS) in cooperation with the Arizona Department of Water Resources; in 1983, the Bureau of Indian Affairs joined the cooperative effort. Since 1983, the Navajo Tribal Utility Authority (NTUA); Peabody Coal Company; the Hopi Tribe; and the Western Navajo Agency, Chinle Agency, and Hopi Agency of the Bureau of Indian Affairs have assisted in the collection of ground-water data.

Purpose and Scope of the Report

This report describes the results of ground-water, surface-water, and water-chemistry monitoring in the Black Mesa area from January to December 1997. The monitoring is designed to determine the effects of industrial and municipal pumpage from the N aquifer on water levels, stream and spring discharge, and water chemistry. Data-collection efforts include continuous and periodic measurements of ground water and surface water in the Black Mesa area. Ground-water data from wells completed in the N aquifer include pumpage, water levels, and water chemistry. Surface-water data include discharge measurements at a continuous-record site.

Previous Investigations

Fifteen progress reports have been prepared by the U.S. Geological Survey on the monitoring phase of the program (U.S. Geological Survey, 1978; G.W. Hill, hydrologist, written commun., 1982, 1983; Hill, 1985; Hill and Whetten, 1986; Hill and Sottilare, 1987; Hart and Sottilare, 1988, 1989; Sottilare, 1992; Littin, 1992, 1993; Littin and Monroe, 1995a, b; 1996, 1997). Most of the data obtained from the monitoring program are contained in these reports except for stream-discharge and sediment-discharge data from Moenkopi Wash collected before the 1986 water year; those data were published in U.S. Geological Survey (1963–64a, b; 1965–74a, b; 1976–83; White and Garrett, 1984, 1986, 1987, and 1988). Eychaner (1983) describes the results of mathematical-model simulations of the flow of ground water in the N aquifer. The model was converted to a new model program and recalibrated by using revised estimates of selected aquifer characteristics and a finer spatial grid (Brown and Eychaner, 1988). Kister and Hatchett (1963) show selected chemical analyses of ground water from wells and springs throughout the Navajo and Hopi Indian Reservations. Cooley and others (1969) provide a detailed description of the regional hydrogeology.

HYDROLOGIC-DATA COLLECTION

In 1997, activities of the monitoring program included metered and estimated ground-water withdrawals, measurements of ground-water levels, flow measurements of springs and surface water, and collection of water-chemistry samples to detect changes in the hydrologic conditions in the N aquifer. Ground-water withdrawals, continuous-record water-level data from observation wells, and surface-water discharge data were collected from January to December 1997. Measurements of annual ground-water levels were made mostly between November and December 1997. Some water levels were measured during the first quarter of 1998 owing to adverse weather and field conditions. Chemical data are from ground-water samples collected in December 1997.

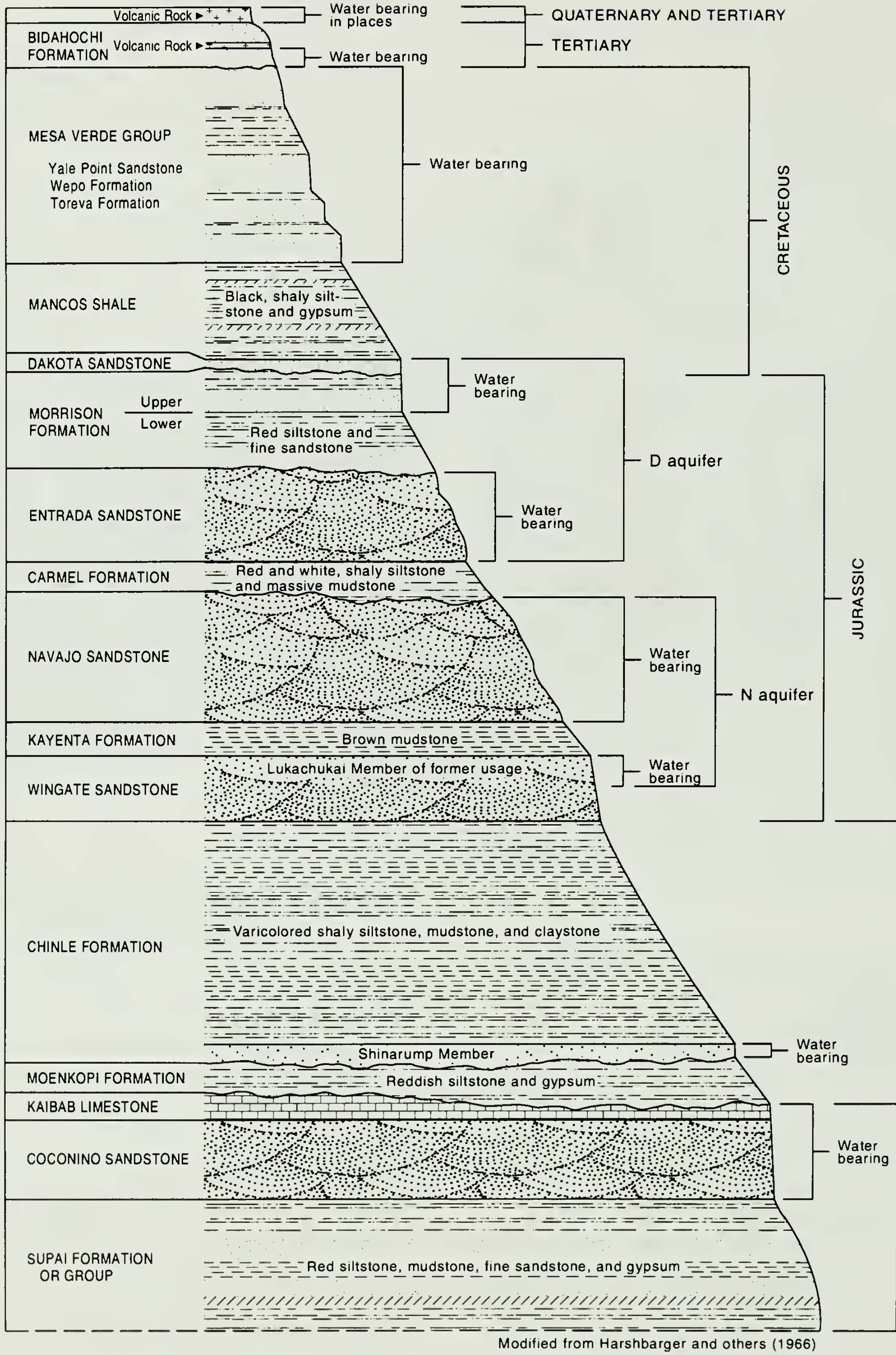


Figure 2. Rock formations of the Black Mesa area. The N aquifer is approximately 1,000 feet thick.

Withdrawals from the N Aquifer

Withdrawals from the N aquifer are separated into three categories—(1) industrial use from the confined part of the aquifer, (2) municipal use from the confined part of the aquifer, and (3) municipal use from the unconfined part of the aquifer (table 1, fig. 3). The industrial category includes eight wells at the Peabody Coal Company well field in northern Black Mesa (fig. 4). The Bureau of Indian Affairs, Navajo Tribal Utility Authority, and the Hopi Tribe operate about 70 municipal wells that are in categories 2 and 3. Withdrawals from wells equipped with windmills are neither measured nor estimated.

Withdrawals from the N aquifer were compiled on the basis of metered and estimated data (tables 1 and 2). In some areas, only partial data were available because of meter malfunctions, and pumpage was either prorated, based on electrical usage, or computed on a per capita basis of 40 gallons per day (gal/d). The per capita consumption is based on pumpage data and population figures (Arizona Department of Economic Security, Population statistics of the Navajo and Hopi Reservations, 1990 census, unpublished data, 1991) for areas without commercial water use.

The total ground-water withdrawal in 1997 was about 7,090 acre-ft (table 1), which is less than a 1-percent increase from total withdrawals in 1996. Pumpage from the confined part of the aquifer increased by about 2 percent to 5,510 acre-ft, and pumpage from the unconfined part of the aquifer decreased by about 4 percent to 1,580 acre-ft. Industrial pumpage accounted for about

Table 1. Withdrawals from the N aquifer, 1965–97

[Values are rounded to the nearest 10 acre-feet. Data for 1965–79 from Eychaner (1983)]

		Municipal[2,3]					Municipal[2,3]		
Year	Indus-trial[1]	Con-fined	Uncon-fined	Total with-drawals	Year	Indus-trial[1]	Con-fined	Uncon-fined	Total with-drawals
1965	0	50	20	50	1982	4,740	870	960	6,570
1966	0	110	30	140	1983	4,460	1,360	1,280	7,100
1967	0	120	50	170	1984	4,170	1,070	1,400	6,640
1968	100	150	100	350	1985	2,520	1,040	1,160	4,720
1969	40	200	100	340	1986	4,480	970	1,260	6,710
1970	740	280	150	1,170	1987	3,830	1,130	1,280	6,240
1971	1,900	340	150	2,390	1988	4,090	1,250	1,310	6,650
1972	3,680	370	250	4,300	1989	3,450	1,070	1,400	5,920
1973	3,520	530	300	4,350	1990	3,430	1,170	1,210	5,810
1974	3,830	580	360	4,770	1991	4,020	1,140	3,360	8,520
1975	3,500	600	510	4,610	1992	3,820	1,180	1,410	6,410
1976	4,180	690	640	5,510	1993	3,700	1,250	1,570	6,520
1977	4,090	750	730	5,570	1994	4,080	1,210	1,600	6,890
1978	3,000	830	930	4,760	1995	4,340	1,220	1,510	7,070
1979	3,500	860	930	5,290	1996	4,010	1,380	1,650	7,040
1980	3,540	910	880	5,330	1997	4,130	1,380	1,580	7,090
1981	4,010	960	1,000	5,970					

NOTE: Total withdrawals in Littin and Monroe (1996) were for the confined part of the aquifer.

[1]Metered pumpage from the confined part of the aquifer by Peabody Coal Company at its mine on Black Mesa.

[2]Does not include withdrawals from the wells equipped with windmills.

[3]Includes estimated pumpage, 1965–73, and metered pumpage, 1974–79, at Tuba City; metered pumpage at Kayenta and estimated pumpage at Chilchinbito, Rough Rock, Piñon, Keams Canyon, and Kykotsmovi before 1980; metered and estimated pumpage furnished by the Navajo Tribal Utility Authority and the Bureau of Indian Affairs and collected by the U.S. Geological Survey, 1980–85; and metered pumpage furnished by the Navajo Tribal Utility Authority, the Bureau of Indian Affairs, various Hopi Village Administrations, and the U.S. Geological Survey, 1986–97.

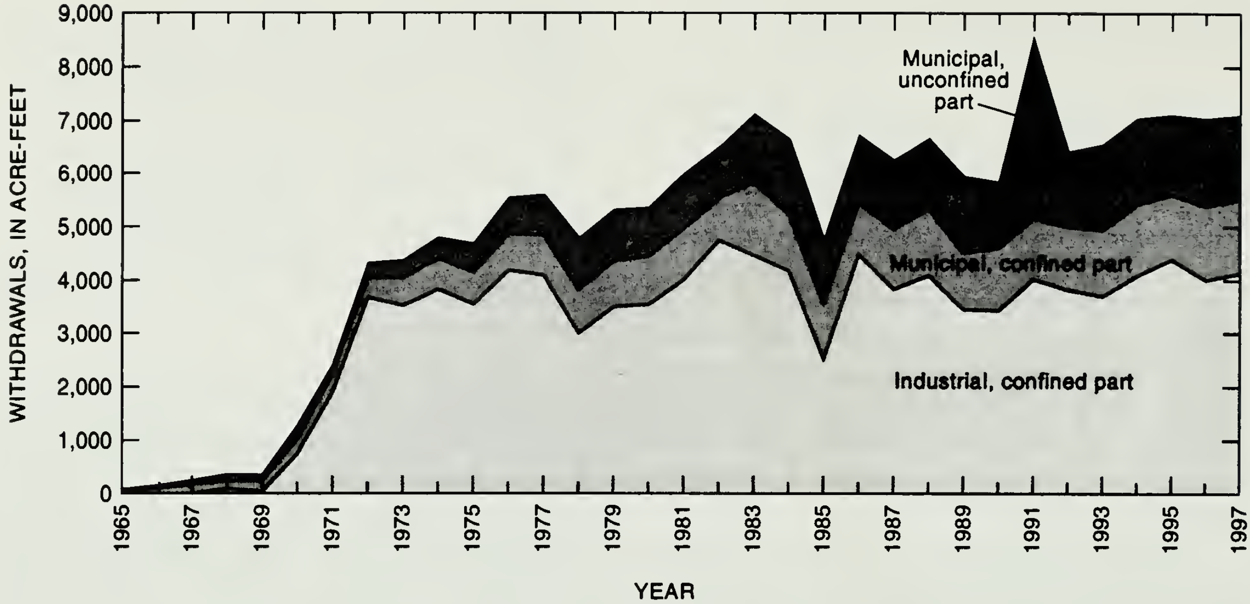


Figure 3. Withdrawals from the N aquifer, 1965–97.

4,130 acre-ft, or about 58 percent of the total withdrawal, as compared with 57 percent in 1996. Municipal pumpage accounted for about 2,960 acre-ft and represents 42 percent of the total withdrawal as compared with 43 percent in 1996.

Ground-Water Levels

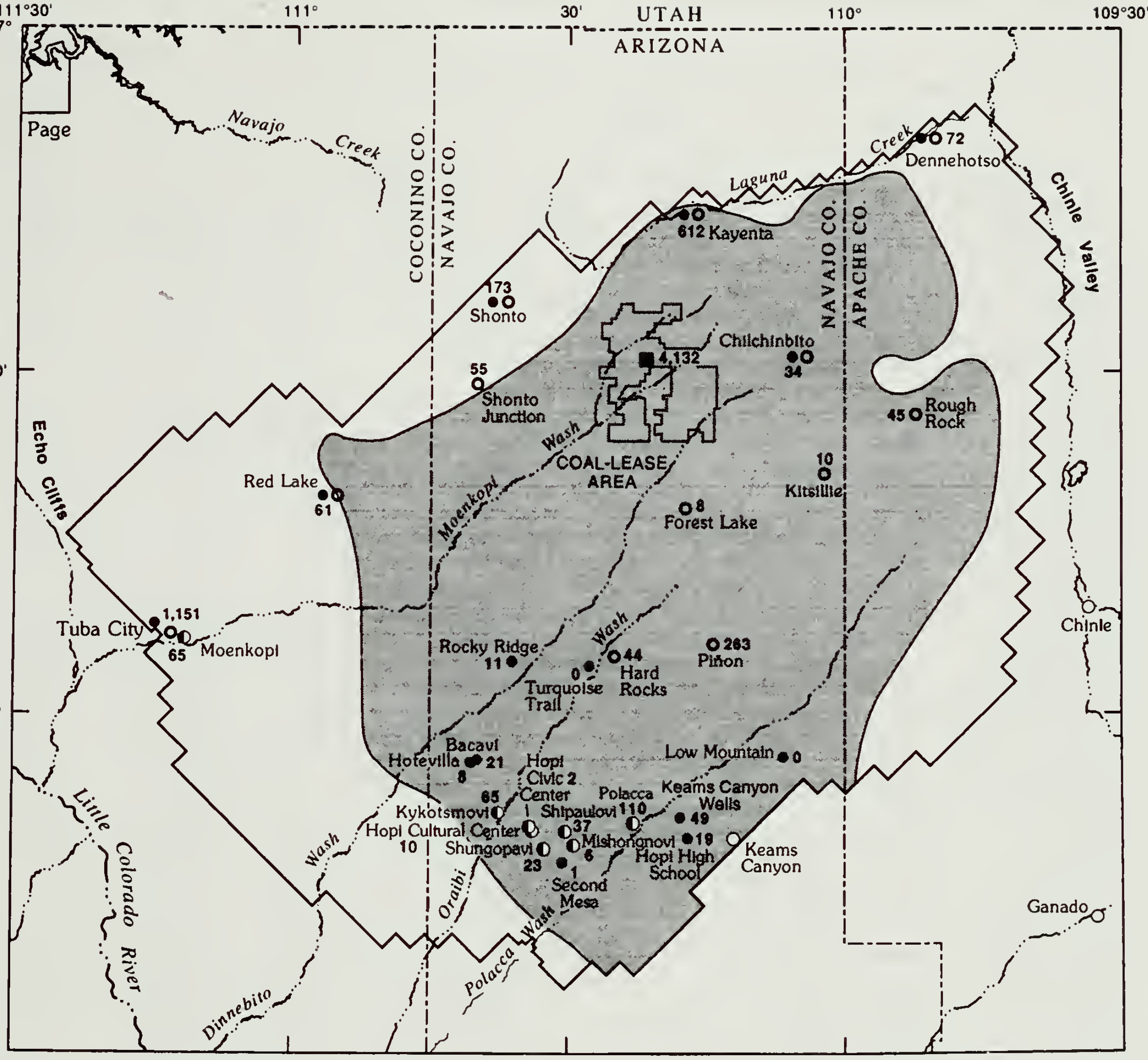
Ground water occurs under confined or artesian conditions in the central part of the study area and under unconfined or water-table conditions around the periphery (fig. 5). Annual ground-water levels were obtained from 27 of 33 municipal and stock wells (table 3). Water-level changes from the earliest available data through 1997 ranged from a rise of about 74 ft at well PM2 at Rocky Ridge to a decline of about 114 ft at Piñon well PM6. In 1997, the maximum annual recorded rise in water level in the Black Mesa area was 146.5 ft at well Rocky Ridge PM2. The maximum annual recorded water-level decline in 1997 was 6.7 ft at well 9Y-95 near Rough Rock. Water-level declines in the confined area from 1996 to 1997 were measured in 5 of 12 wells; however, the median change was a rise of about 0.2 ft as compared with a decline of 2.8 ft from 1995 to 1996. Water-level declines in the unconfined area from 1996 to 1997 were measured in 7 of 15 wells, and the median change was 0.0 ft as compared with a decline of 0.5 ft from 1995 to 1996.

Hydrographs of measured water levels in the six continuous-record observation wells (BM1 through BM6) are based on annual and continuous-record data beginning about 1963 at well BM3 (fig. 6). Water-level data for wells BM1, BM2, BM4, and BM5 began in 1972; water-level data for well BM6 began in 1977. Well-construction data for these wells are given in table 4.

Since 1972, water levels in wells completed in the unconfined part of the N aquifer have risen by 0.1 ft in BM1 and 1.0 ft in BM4 (fig. 6); however, during the same period, water levels in wells completed in the confined part of the N aquifer have declined by about 73 ft in well BM2, 90 ft in well BM3, and 74 ft in well BM5. Well BM6, also completed in the confined part of the N aquifer, has recorded a water-level decline of 87 ft since 1977. Records for the oldest well, BM3, indicate a water-level decline of 94 ft since 1963.

Surface-Water Discharge

Outflow from the N aquifer occurs mainly as surface flow in Moenkopi Wash and Laguna Creek, and as springs near the boundaries of the aquifer



Base from U.S. Geological Survey digital data, 1:100,000, 1980
Lambert Conformal Conic projection
Standard parallels 29°30' and 45°30', central meridian -96°00'

0 — 25 MILES
0 — 25 KILOMETERS

Modified from Brown and Eychaner (1988)

EXPLANATION

BOUNDARY BETWEEN CONFINED AND UNCONFINED CONDITIONS APPROXIMATE—From Eychaner (1983)

CONFINED

UNCONFINED

BOUNDARY OF MATHEMATICAL MODEL—From Eychaner (1983)

WELL-SYSTEM OWNER

- ● Bureau of Indian Affairs
- ○ Navajo Tribal Utility Authority
- ◐ Hopi Tribe
- ■ Peabody Coal Company (8 wells)

○8 Forest Lake — WITHDRAWALS FROM THE N AQUIFER—Forest Lake, is the village name; 8, is the total withdrawal in acre-feet for 1997 location. The total is cumulative at locations served by multiple well owners

Figure 4. Location of well systems monitored for withdrawals from the N aquifer, 1997.

Table 2. Withdrawals from the N aquifer by well system, 1997

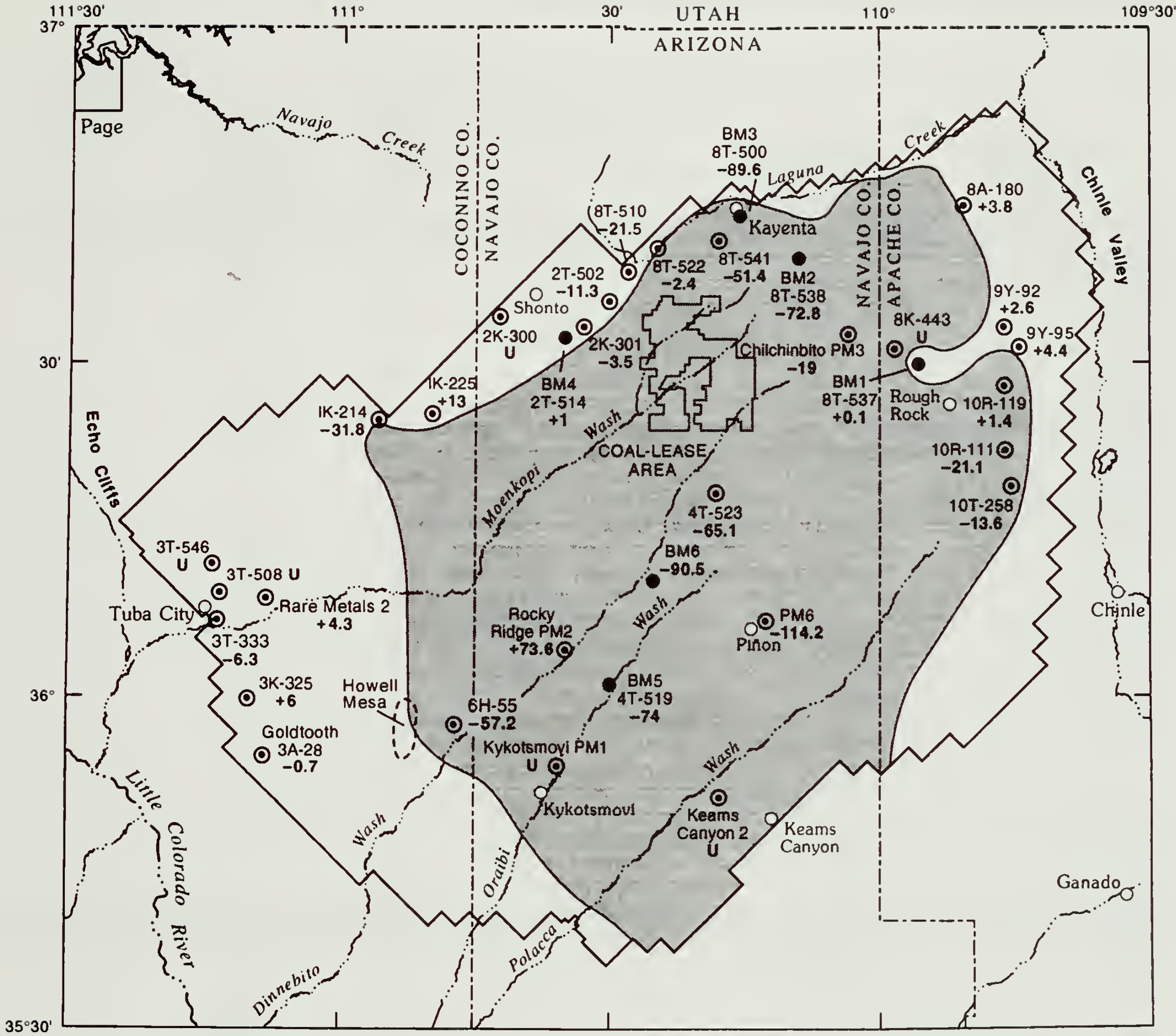
[Withdrawals, in acre-feet, are from flowmeter measurements. BIA, Bureau of Indians Affairs, NTUA, Navajo Tribal Utility Authority; USGS, U.S. Geological Survey; Peabody Coal Company; Hopi, Hopi Village Administrations]

Well system (one or more wells)	Owner	Source of data	Withdrawals		Well system (one or more wells)	Owner	Source of data	Withdrawals	
			Confined aquifer	Unconfined aquifer				Confined aquifer	Unconfined aquifer
Chilchinbito	BIA	USGS/BIA	3.8		Kayenta	NTUA	NTUA	542.3	
Dennehotso	BIA	USGS/BIA		34.4	Kitsillie	NTUA	NTUA	9.9	
Hopi High School	BIA	USGS/BIA	19.3		Piñon	NTUA	NTUA	263.1	
Hotevilla	BIA	USGS/BIA	8.2		Red Lake	NTUA	NTUA		55.4
Kayenta	BIA	USGS/BIA	70.4		Rough Rock	NTUA	NTUA	16.0	
Keams Canyon	BIA	USGS/BIA	49.1		Shonto	NTUA	NTUA		14.2
Low Mountain	BIA	USGS/BIA	[1]0		Shonto Junction	NTUA	NTUA		55.3
Piñon	BIA	USGS/BIA	[1]0		Tuba City	NTUA	NTUA		983.2
Red Lake	BIA	USGS/BIA		5.7	Mine Well Field	Peabody	Peabody	[3]4,132.2	
Rocky Ridge	BIA	USGS/BIA	11.3		Bacavi	Hopi	USGS/Hopi	21.4	
Rough Rock	BIA	USGS/BIA	29.3		Hopi Civic Center	Hopi	USGS/Hopi	1.8	
Second Mesa	BIA	USGS/BIA	[2]1.0		Hopi Cultural Center	Hopi	USGS/Hopi	9.9	
Shonto	BIA	USGS/BIA		159.2	Kykotsmovi	Hopi	USGS/Hopi	65.1	
Tuba City	BIA	USGS/BIA		167.7	Mishongnovi	Hopi	USGS/Hopi	5.8	
Turquoise Trail	BIA	BIA Roads	0		Moenkopi	Hopi	USGS/Hopi		[4]65.4
Chilchinbito	NTUA	NTUA	30.0		Polacca	Hopi	USGS/Hopi	[5]110	
Dennehotso	NTUA	NTUA		37.1	Shipaulovi	Hopi	USGS/Hopi	36.6	
Forest Lake	NTUA	NTUA	8.4		Shungopovi	Hopi	USGS/Hopi	22.7	
Hard Rocks	NTUA	NTUA	43.5						

[1]Well taken out of service.
[2]Second Mesa bought 5.8 acre-feet of water from Shipaulovi.
[3] Industrial pumpage.
[4]Total pumpage may be greater than shown owing to possible meter malfunction.
[5] Estimated. Well PM4 not metered. Total includes 70 acre-feet from wells 5 and 6 and may include D aquifer water.

(Davis and others, 1963). Discharge data were collected at the continuous-record streamflow-gaging stations, Moenkopi Wash at Moenkopi (09401260; fig. 7, table 5), Laguna Creek at Dennehotso (09379180; fig. 7, table 6), Dinnebito Wash near Sand Springs (09401110; fig. 7, table 7); and Polacca Wash near Second Mesa (09400568; fig. 7, table 8). The Dinnebito and Polacca stations monitor discharge from springs along the southern boundary of Black Mesa. Low-flow calculations for these streams are based on discharge measurements made during November through February 1997. Discharge data collected during these months are considered representative of low flow because the effect of stream loss from evapotranspiration and gain from snowmelt and rainfall (which generally occurs during temperate months) is minimized.

The measured low-flow discharge at the Moenkopi station ranged from 1.6 to 2.0 ft^3/s. The mean daily discharge for the same period ranged from 1.2 to 2.9 ft^3/s and is based on continuous-record data. Mean daily discharges for previous



Base from U.S. Geological Survey digital data, 1:100,000, 1980
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Standard parallels 29°30' and 45°30', central meridian -96°00'

Modified from Brown and Eychaner (1988)

0 — 25 MILES

0 — 25 KILOMETERS

EXPLANATION

BOUNDARY BETWEEN CONFINED AND UNCONFINED CONDITIONS APPROXIMATE—From Eychaner (1983)

CONFINED

UNCONFINED

BOUNDARY OF MATHEMATICAL MODEL—From Eychaner (1983)

4T-523 -65.1 — WELL IN WHICH DEPTH TO WATER WAS MEASURED ANNUALLY—First entry, 4T-523, is Bureau of Indian Affairs site number; second entry, **-65.1**, is change in water level, in feet, between measurements made during the prestress period and measurements made during 1997. **U**, unable to measure

BM2 8T-538 -72.8 — CONTINUOUS WATER-LEVEL RECORDING SITE (OBSERVATION WELL) MAINTAINED BY THE U.S. GEOLOGICAL SURVEY—First entry, BM2, is U.S. Geological Survey well number; second entry, 8T-538, is Bureau of Indian Affairs site number; third entry, **-72.8**, is change in water level, in feet, from earliest available date to 1997

Figure 5. Water-level changes in wells completed in the N aquifer from the start of data collection through 1997.

Table 3. Water-level changes in wells completed in the N aquifer

[Do., ditto; ---, no data]

Well system or location name	U.S. Bureau of Indian Affairs site number	Change in water level from preceding water year, in feet		Water level, in feet below land surface, 1997	Prestress[1] water level, in feet below land surface	Change in water level from prestress to 1997, in feet[2]
		1996	1997			
Unconfined						
BM1[3]	8T-537	0	0	373.9	374.0	+0.1
BM4[3]	2T-514	0	0	216.0	217	+1
Cow Springs	1K-225	+0.4	-0.5	47.0	60	+13
Goldtooth	3A-28	-.5	-.6	230.7	230	-.7
Long House Valley	8T-510	-.7	0	120.5	99	-21.5
Marsh Pass	8T-522	-1.3	-.9	127.9	125.5	-2.4
Northeast Rough Rock	8A-180	0	+.1	43.1	46.9	+3.8
Rough Rock	9Y-95	-2.9	-6.7	115.1	119.5	+4.4
Do.	9Y-92	-3.5	+4.4	166.2	168.8	+2.6
Shonto	2K-300	-.2	([4])	([4])	176.5	---
Shonto Southeast	2K-301	-.5	+.3	287.4	283.9	-3.5
Do.	2T-502	-.5	-2.5	417.1	405.8	-11.3
Tuba City	3T-333	-1.2	-.3	29.3	23.0	-6.3
Do.	3K-325	+.1	+.6	202.0	208	+6
Do.	Rare Metals 2	+1.3	-.4	52.7	57	+4.3
Tuba NTUA 1	3T-508	-3.0	([4])	([4])	29.0	---
Tuba NTUA 4	3T-546	-2.4	([4])	([4])	33.7	---
White Mesa Arch	1K-214	+.5	+.6	219.8	188	-31.8
Confined						
BM2[2]	8T-538	-1.6	-2.6	197.8	125.0	-72.8
BM3[2]	8T-500	-2.6	+4.3	149.6	60.0	-89.6
BM5[2]	4T-519	-2.7	-2.4	397.8	323.8	-74.0
BM6[2]	BM6	-3.8	-3.5	826.1	735.6	-90.5
Forest Lake NTUA 1	4T-523	-5.1	-3.7	1,161.1	1,096.0	-65.1
Howell Mesa	6H-55	-.9	+.3	269.2	212	-57.2
Kayenta West	8T-541	-7.0	+17.8	278.4	227	-51.4
Keams Canyon	2	+10.7	([4])	([4])	292.5	---
Kykotsmovi	PM1	([4])	([4])	([4])	220	---
Piñon	PM6	[5]-13.8	-3.8	857.8	743.6	-114.2
Rocky Ridge	PM2	-2.9	+146.5	358.4	432	+73.6
Rough Rock	10R-119	([4])	[5]+.9	255.2	256.6	+1.4
Do.	10T-258	-9.4	+2.7	314.6	301.0	-13.6
Do.	10R-111	+8.2	+.2	191.1	170.0	-21.1
Sweetwater Mesa	8K-443	([4])	([4])	([4])	529.4	---

[1]Prestress refers to the period of record prior to ground-water withdrawals for mining purposes, circa 1968.
[2]Change in water level is reported to the same precision as the prestress water level.
[3]Continuous recorder. Except for well BM3, prestress water levels are based on model simulation.
[4]Unable to measure.
[5]Change in water level from last measurement 2 or more years earlier.

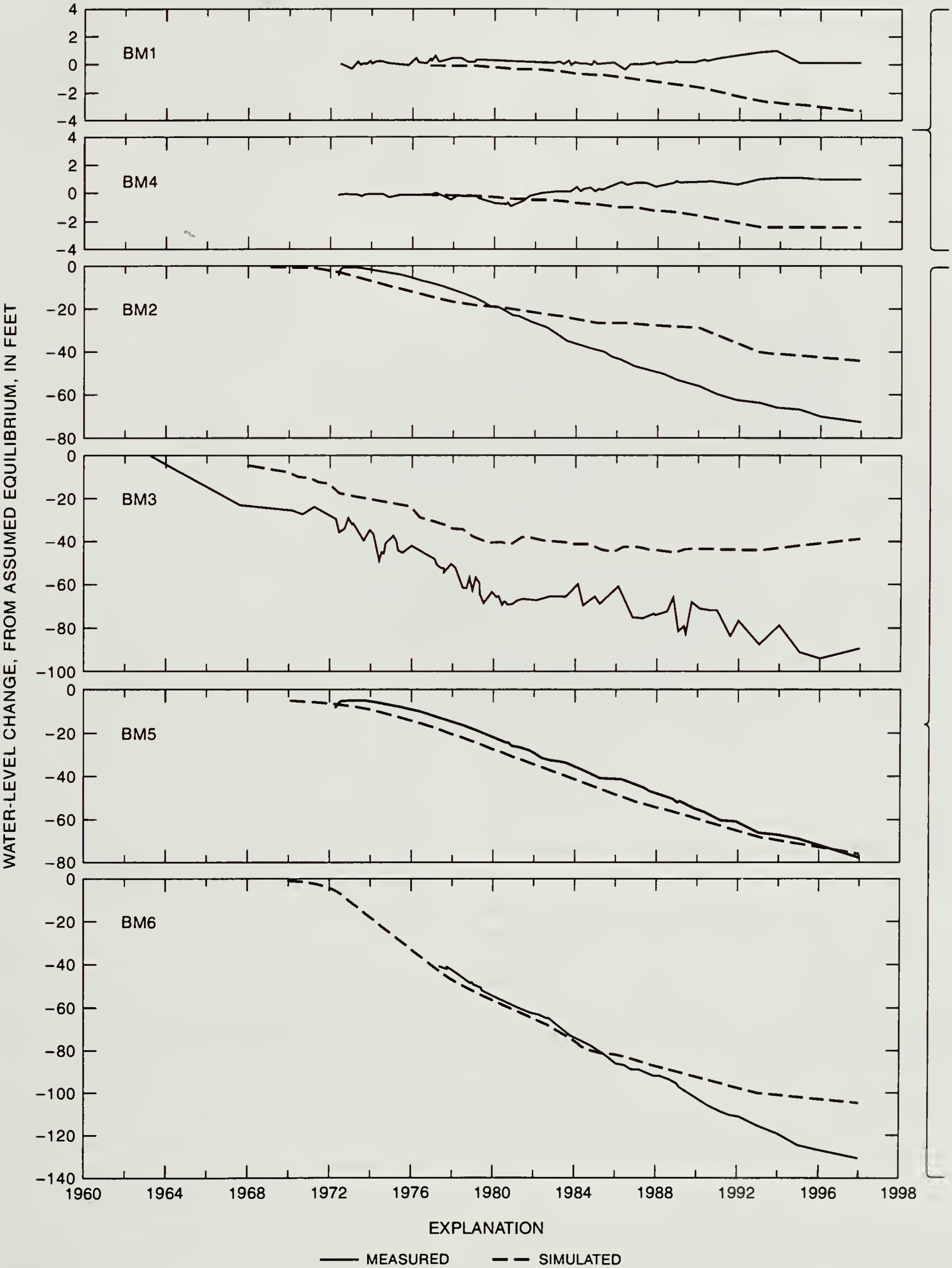

Figure 6. Measured and simulated water-level changes in continuous-record observation wells BM1 through BM6, 1963–97.

Table 4. Well construction data for Black Mesa continuous-record observation wells, BM1–BM6

[Ss, Sandstone; Fm, Formation]

Well name	Date completed	Elevation, in feet	Depth, in feet below land surface	Screened/open interval(s), in feet below land surface	Lithology of screened interval(s)	Static water level, in feet below land surface
BM1	2–1–72	5,865	850	300–360;400–420; 500–520;600–620; 730–780	Navajo Ss (290–640) Kayenta Fm (640–[1])	374
BM2	1–29–72	5,650	1,338	470–1,338	Navajo Ss (45–995) Kayenta Fm (995–1,145) Wingate Ss (1,145–[1])	125
BM3	7–29–59	5,735	868	712–868 (open)	Navajo Ss (155–860) Kayenta Fm (86–[1])	60
BM4	2–15–72	6,345	400	250–400	Navajo Ss (30–[1])	217
BM5	2–25–72	5,858	1,683	1,521–1,683	Navajo Ss (1,520–[1])	323
BM6	1–31–77	6,340	2,507	1,954–2,506 (open)	Navajo Ss (1,950–[1])	736

[1]Total thickness at this location is unknown.

water years have been published by the U.S. Geological Survey (1963–64a, b; 1965–74a, b; and 1976–83), White and Garrett (1984, 1986–88), Wilson and Garrett (1988–89), Boner and others (1989–92), Garrett and Gellenbeck (1991), Smith and others (1993–97), and Tadayon and others (1998). On the basis of these data, the average mean daily discharge (as low flow) in Moenkopi Wash has remained at about 3 ft^3/s since the streamflow-gaging station was installed in 1976. Since 1992, the average mean daily discharge (as low flow) is about 2.7 ft^3/s.

The Laguna Creek streamflow-gaging station became operational in July 1996. The measured low-flow discharge at the Laguna station ranged from 2.3 to 4.2 ft^3/s, which was based on measurements made during November and December[2] 1997. The mean daily discharge for the same period was 3.3 ft^3/s, which was based on continuous-record data.

The Dinnebito and Polacca streamflow-gaging stations became operational in June 1993 and April 1994, respectively, under contract with the Hopi Tribe, and were added to the Black Mesa streamflow-gaging network in October 1996. The measured low-flow discharge ranged from 0.44 to 0.48 ft^3/s at the Dinnebito station and 0.15 to 0.26 ft^3/s at the Polacca station. The average mean daily discharge for Dinnebito Wash during November through February was 0.50 ft^3/s, which was based on continuous-record data for calendar years 1994 through 1997. The average mean daily discharge for Polacca Wash was 0.22 ft^3/s, and was based on continuous-record data for calendar years 1995 through 1997.

Four springs—Burro Spring, an unnamed spring near Dennehotso, Moenkopi School Spring, and Pasture Canyon Spring—were selected for discharge measurements as part of the monitoring program during 1997 (fig 7, table 9). Discharge at Burro Spring was measured at 0.2 gallons per minute (gal/min). Discharge at the unnamed spring near Dennehotso was measured at 25.6 gal/min—an increase of 9.9 gal/min since 1996. Discharge from Moenkopi School Spring was 13.1 gal/min as compared with 10 gal/min measured in 1996. Discharge at Pasture Canyon Spring was measured volumetrically at 40 gal/min at the spring.

[2]Effluent is continuously discharged into Laguna Creek at Kayenta during the winter months according to the Navajo Tribal Utility Authority. Discharge was 0.53 cubic foot per second in November 1994.

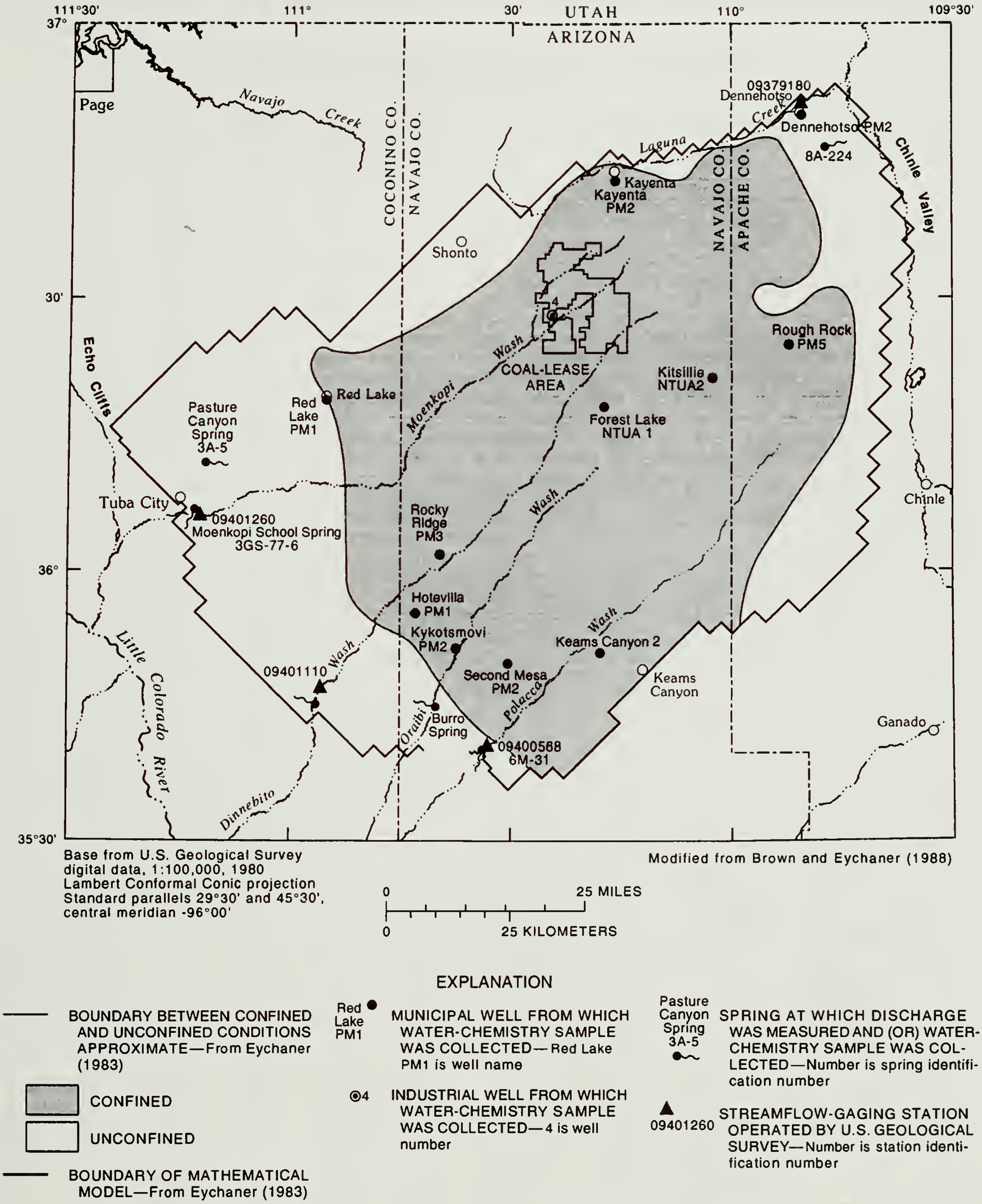

Figure 7. Surface-water and water-chemistry data-collection sites, 1997.

Table 5. Discharge data, Moenkopi Wash at Moenkopi (09401260), calendar year 1997

[---, no data]

DISCHARGE, IN CUBIC FEET PER SECOND, CALENDAR YEAR 1997 DAILY MEAN VALUES												
Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.[1]	Nov.[1]	Dec.[1]
1	2.4	2.4	2.8	2.1	1.7	0.07	0.00	0.59	5.7	0.29	1.6	2.1
2	2.4	2.4	2.0	2.7	1.8	.00	.00	.02	23	5.5	1.6	2.4
3	2.4	2.4	1.9	2.8	1.8	.00	.00	.25	13	648	1.6	2.5
4	2.4	2.4	2.5	4.3	1.8	.00	.00	15	2.8	83	1.7	2.4
5	2.5	2.4	2.6	6.1	1.8	.00	.00	498	102	3.7	[2]2.0	2.8
6	3.5	2.5	1.8	6.8	1.5	.00	.00	9.0	14	3.7	[2]2.1	3.0
7	3.2	3.2	1.6	3.1	1.2	.00	.00	2.8	8.9	644	2.1	2.8
8	2.1	4.3	1.9	2.7	.94	.60	.00	1.5	4.5	424	2.1	2.4
9	2.2	3.3	2.0	2.8	.76	.58	.00	1.3	6.7	22	2.1	2.5
10	2.7	2.8	1.6	2.8	1.2	.06	.00	1.0	3.4	4.7	2.1	3.2
11	2.8	2.2	1.5	2.6	1.6	.00	.00	.91	2.2	2.1	2.2	3.9
12	2.9	2.4	1.9	2.4	1.3	.00	.00	.94	10	1.4	2.5	2.1
13	2.8	2.3	1.7	2.2	.74	.00	.00	.69	4.0	1.3	2.8	2.4
14	5.4	2.3	1.3	2.3	.74	.00	.00	.30	69	1.3	2.6	2.3
15	3.0	3.7	1.3	1.8	.74	.00	.00	.63	117	1.3	3.0	2.6
16	1.9	2.9	1.0	1.9	.77	.00	.00	.29	829	1.3	2.5	2.5
17	2.6	2.4	1.4	1.6	.77	.00	.00	.30	16	1.3	2.1	2.5
18	2.3	2.4	1.8	1.5	.54	.00	.00	2.4	2.9	1.3	2.1	2.2
19	2.7	2.1	1.9	1.3	.42	.00	.00	1.5	7.9	1.3	2.1	2.9
20	3.1	2.1	1.7	1.1	.53	.00	.00	1.1	7.1	1.3	2.1	3.7
21	2.9	2.0	1.2	1.1	.82	.00	.00	.70	1.9	1.3	2.1	3.7
22	2.9	2.3	.92	.91	1.9	.00	.00	.56	.84	1.3	1.8	3.0
23	3.5	2.5	1.1	2.0	1.3	.00	6.7	.37	.56	1.6	1.8	2.7
24	3.4	2.1	1.4	2.4	.91	.00	4.5	.05	.50	1.5	1.8	2.9
25	3.1	2.4	1.2	2.4	.91	.00	1.3	.00	.46	1.3	1.8	2.6
26	3.0	2.7	1.1	2.1	1.0	.00	.05	.00	.61	1.3	1.9	1.5
27	4.6	1.8	1.4	1.9	.83	.00	.00	.00	.46	1.4	2.1	2.3
28	3.2	2.0	1.9	2.0	.93	.00	.00	.00	.45	1.6	2.3	2.4
29	3.0	---	1.8	2.0	.68	.00	63	.00	.33	1.6	2.1	2.1
30	2.5	---	2.1	1.8	.50	.00	5.6	.00	.29	1.6	2.1	2.4
31	2.1	---	1.9	---	.57	---	1.3	24	---	1.7	---	2.7
TOTAL	89.5	70.7	52.22	73.51	33.00	1.31	82.45	564.20	1,255.50	1,868.99	62.8	81.5
MEAN	2.89	2.52	1.68	2.45	1.06	.044	2.66	18.2	41.8	60.3	2.1	2.63
MAX	5.4	4.3	2.8	6.8	1.9	.60	63	498	829	648	3.0	3.9
MIN	1.9	1.8	.92	.91	.42	.00	.00	.00	.29	.29	1.6	1.5
AC-FT	178	140	104	146	65	2.6	164	1,120	2,490	3,710	125	162

CALENDAR YEAR 1997 TOTAL 4,235.68 MEAN 11.60 MAXIMUM 829 MINIMUM 0.00 ACRE-FT 8,400

[1]Month in which data are provisional, subject to revision.

[2]Estimated.

Table 6. Discharge data, Laguna Creek at Dennehotso (09379180), calendar year 1997

[---, no data]

DISCHARGE, IN CUBIC FEET PER SECOND, CALENDAR YEAR 1997 DAILY MEAN VALUES												
Day	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**[1]	**Nov.**[1]	**Dec.**[1]
1	1.6	[2]2.0	3.0	.30	0.00	0.00	0.00	0.54	8.6	1.7	3.2	1.4
2	1.2	[2]1.5	1.9	[2]1.5	.00	.00	.00	2.0	[2]115	1.2	3.4	[2]1.6
3	1.7	[2]2.0	4.2	11	.00	.00	.00	1.3	28	124	4.0	1.5
4	6.8	[2]2.0	3.8	9.0	.00	.00	.00	6.9	52	32	4.6	[2].60
5	17	[2]2.0	2.9	16	.00	.00	.00	428	36	7.7	[2]4.8	.24
6	2.4	[2]1.0	1.4	8.2	.00	.00	.00	24	19	3.7	[2]4.6	.85
7	1.1	[2]1.0	2.6	4.8	.00	.00	.00	6.8	8.4	5.8	4.2	1.7
8	.09	[2]1.0	2.6	3.2	.00	.00	.00	4.6	5.3	120	4.0	3.4
9	.11	[2]1.0	2.3	2.6	.00	.00	.00	4.1	4.9	12	4.0	6.0
10	.00	[2]1.5	2.0	2.1	.00	.00	.00	35	4.7	8.4	4.0	4.6
11	.00	[2]1.5	1.5	.98	.00	.00	.00	623	5.4	5.8	4.4	2.5
12	.00	[2]1.5	.95	.11	.27	.00	.00	568	7.0	4.1	5.4	1.3
13	2.9	[2]5.0	.68	.77	.08	.00	.00	22	9.2	3.0	5.5	1.5
14	4.3	2.7	1.1	.38	.00	.00	.00	8.6	40	1.9	6.5	.60
15	.57	4.2	1.5	1.2	.00	.00	.00	5.3	76	4.3	6.2	.44
16	.07	4.8	1.3	.80	.00	.00	.00	4.4	498	3.6	5.2	2.7
17	.00	4.1	.52	.41	.00	.00	.00	3.9	35	2.3	3.6	.74
18	1.5	3.1	.33	.08	.00	.00	.00	1.3	9.9	1.9	2.9	1.2
19	.00	2.5	.26	.00	.00	.00	.00	.07	6.1	3.7	4.6	2.2
20	.42	2.0	.19	.02	.01	.00	.00	.00	5.6	3.3	4.7	2.5
21	.00	1.9	.04	.00	9.9	.00	.00	4.4	3.7	3.1	6.1	1.8
22	.81	1.4	.02	.00	8.0	.00	.00	2.2	3.3	2.9	4.5	[2]6.6
23	1.8	1.9	.02	.00	.77	.00	143	2.4	2.3	3.1	[2]3.7	6.2
24	2.4	2.7	.00	.00	.03	.00	33	4.7	1.2	3.4	3.1	8.6
25	1.7	4.2	.73	.00	.00	.00	4.6	5.0	1.4	3.3	[2]3.5	16
26	2.0	6.2	.01	.09	.00	.00	.51	20	2.3	3.8	3.1	6.0
27	[2]13	1.1	.00	1.5	.00	.00	.05	284	2.2	2.4	2.3	22
28	[2]2.0	6.9	.00	.58	.00	.00	.00	213	.93	4.2	1.7	12
29	[2]2.0	---	.00	.03	.00	.00	34	70	.05	3.9	1.8	3.8
30	[2]2.0	---	.00	.00	.00	.00	15	11	4.4	3.9	1.7	4.6
31	[2]2.0	---	.39	---	.00	---	3.1	8.4	---	3.4	---	6.7
TOTAL	71.47	72.7	36.24	65.65	19.06	0.00	233.26	2,374.91	995.88	387.8	121.3	131.9
MEAN	2.31	2.60	1.17	2.19	.61	.00	7.52	76.6	33.2	12.5	4.04	4.25
MAX	17	6.9	4.2	16	9.9	.00	143	623	498	124	6.5	22
MIN	.00	1.0	.00	.00	.00	.00	.00	.00	.05	1.2	1.7	.24
AC-FT	142	144	72	130	38	.00	463	4,710	1,980	769	241	262

CALENDAR YEAR 1997 TOTAL 4,510.17 MEAN 12.3 MAXIMUM 623 MINIMUM 0.00 ACRE-FT 8,940

[1]Month in which data are provisional, subject to revision.

[2]Estimated.

Table 7. Discharge data, Dinnebito Wash near Sand Springs (09401110), calendar year 1997

[---, no data]

DISCHARGE, IN CUBIC FEET PER SECOND, CALENDAR YEAR 1997
DAILY MEAN VALUES

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.[1]	Nov.[1]	Dec.[1]
1	0.41	0.41	0.36	0.27	0.24	0.15	0.19	0.89	16	0.28	0.34	0.47
2	.42.	.41	.36	.33	.25	.15	.19	.45	120	.39	.35	.44
3	.43	.41	.34	.35	.26	.16	.18	[2]110	38	231	.36	.45
4	.42	.40	.34	.48	.26	.15	.19	[2]350	.47	66	.39	.39
5	.48	.40	.33	.41	.26	.14	.18	[2]379	2.9	3.8	.37	.44
6	.42	.40	.37	.30	.25	.17	.17	30	242	.34	.40	.48
7	.36	.36	.38	.29	.24	.30	.16	2.5	27	11	.38	.56
8	.36	.42	.37	.28	.23	.25	.17	.24	9.3	[2]732	.38	.60
9	.36	.43	.38	.22	.24	.21	.17	[2].20	5.6	210	.36	.46
10	.39	.38	4.6	.24	.23	.19	.16	[2].20	[2].20	2.9	.37	.43
11	.41	.39	16	.27	.24	.18	.15	[2].20	[2].20	.62	.38	.37
12	.42	.38	13	.26	.23	.17	.15	[2].70	[2]1.9	.21	.69	.35
13	.48	.37	8.6	.26	.22	.16	.16	[2].20	53	.18	.62	.38
14	.52	.40	4.9	.27	.21	.16	.16	[2].20	6.5	.16	.80	.42
15	.30	.40	3.3	.27	.21	.20	.17	[2].20	23	.17	.83	.43
16	.36	.41	.48	.26	.20	.22	.16	[2].20	213	.19	.47	.44
17	.36	.40	.30	.26	.20	.21	.16	[2].20	[2]36	.24	.47	.48
18	.41	.31	.27	.25	.20	.21	.15	[2].20	[2]10	.25	.46	.50
19	.41	.39	.27	.23	.20	.19	.16	[2].20	[2]121	.29	.48	.52
20	.44	.37	.27	.24	.21	.18	.19	[2].20	[2]27	.36	.45	.52
21	.45	.33	.27	.23	.29	.18	.19	[2].20	[2]1.1	.33	.45	.55
22	.45	.35	.27	.24	.18	.19	.41	[2].52	[2].40	.37	.46	.96
23	.48	.38	.25	.27	.20	.19	.24	[2].20	[2].30	.36	.47	.97
24	.47	.40	.24	.30	.15	.19	.21	[2].35	.33	.32	.48	.55
25	.45	.44	.23	.27	.16	.20	2.8	[2].25	.30	.31	.49	.39
26	.48	.37	.26	.25	.14	.20	.50	[2].20	.29	.32	.46	.30
27	.46	.41	.24	.24	.16	.19	.33	[2].17	.30	.38	.91	.36
28	.42	.47	.24	.22	.17	.18	26	.16	.36	.38	.47	.43
29	.41	---	.24	.21	.17	.19	60	.15	.28	.36	.45	.44
30	.39	---	.27	.23	.16	.19	27	.15	.27	.40	.49	.49
31	.41	---	.26	---	.17	---	4.7	126	---	.36	---	.53
TOTAL	13.03	10.99	57.99	8.20	6.53	5.65	125.75	1,004.33	957.00	1,264.27	14.48	15.10
MEAN	.42	.39	1.87	.27	.21	.19	4.06	32.4	31.9	40.8	.48	.49
MAX	.52	.47	16	.48	.29	.30	60	379	242	732	.91	.97
MIN	.30	.31	.23	.21	.14	.14	.15	.15	.20	.16	.34	.30
AC-FT	26	22	115	16	13	11	249	1,990	1,900	2,510	29	30

CALENDAR YEAR 1997 TOTAL 3,483.32 MEAN 9.54 MAXIMUM 732 MINIMUM 0.14 ACRE-FT 6,910

[1]Month in which data are provisional, subject to revision.

[2]Estimated.

Table 8. Discharge data, Polacca Wash near Second Mesa (09400568), calendar year 1997

[---, no data]

DISCHARGE, IN CUBIC FEET PER SECOND, CALENDAR YEAR 1997 DAILY MEAN VALUES												
Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.[1]	Nov.[1]	Dec.[1]
1	0.17	0.18	0.30	0.16	0.10	0.08	0.04	0.04	102	0.07	0.18	0.20
2	.19	.18	.28	.17	.11	.07	.04	.04	57	.07	.18	.18
3	.29	.18	.22	.26	.10	.07	.04	26	9.0	25	.18	.18
4	.20	.20	.22	.35	.10	.07	.04	18	.93	24	.19	.18
5	.35	.24	.23	.41	.10	.07	.04	256	24	5.7	.17	.20
6	.25	.23	.24	.20	.09	.07	.04	327	221	.94	.18	.22
7	.17	.24	.24	.17	.09	.08	.04	55	17	1.7	.18	.24
8	.17	.26	.23	.16	.09	.08	.04	8.9	9.1	121	.18	.24
9	.17	.25	.23	.13	.09	.07	.04	3.1	2.5	35	.18	.20
10	.19	.24	.24	.12	.09	.07	.04	.51	.14	4.8	.18	.19
11	.18	.24	.22	.17	.08	.06	.03	.20	.09	.79	.19	.17
12	.18	.24	.21	.17	.07	.06	.03	.10	4.5	.14	.25	.17
13	.27	.23	.20	.15	.08	.06	.03	.09	1.4	.13	.21	.17
14	.34	.23	.21	.14	.09	.06	.04	.08	53	.13	.29	.19
15	.15	.25	.20	.14	.09	.06	.04	.07	6.7	.13	.29	.20
16	.18	.26	.19	.13	.09	.06	.03	.07	114	.13	.20	.20
17	.16	.26	.20	.13	.09	.06	.03	.97	19	.14	.19	.21
18	.17	.24	.19	.12	.09	.06	.03	.61	1.4	.14	.19	.24
19	.18	.24	.20	.12	.10	.06	.03	.08	.12	.14	.19	.25
20	.22	.24	.19	.11	.10	.05	.04	.07	.07	.14	.19	.24
21	.26	.23	.19	.11	.14	.05	.04	.07	.07	.15	.18	.27
22	.20	.24	.18	.11	.17	.05	.05	.07	.07	.20	.19	.26
23	.22	.26	.17	.14	.13	.05	.04	.06	.07	.16	.20	.26
24	.17	.26	.16	.15	.12	.05	.04	2.6	.07	.17	.21	.21
25	.18	.30	.16	.23	.11	.05	.03	1.2	.07	.15	.21	.17
26	.26	.28	.18	.13	.11	.05	.03	27	.08	.16	.22	.16
27	.22	.41	.18	.12	.11	.05	.04	48	.07	.17	.32	.15
28	.18	.46	.15	.11	.11	.04	.04	46	.07	.18	.22	.17
29	.18	---	.15	.10	.10	.04	.04	5.6	.07	.17	.19	.18
30	.17	---	.16	.10	.10	.04	.04	9.9	.07	.17	.19	.20
31	.18	---	.17	---	.09	---	.04	108	---	.18	---	.23
TOTAL	6.40	7.07	6.29	4.81	3.13	1.79	1.16	945.43	643.66	222.15	6.12	6.33
MEAN	.21	.25	.20	.16	.10	.060	.037	30.5	21.5	7.17	.20	.20
MAX	.35	.46	.30	.41	.17	.08	.05	327	221	121	.32	.27
MIN	.15	.18	.15	.10	.07	.04	.03	.04	.07	.07	.17	.15
AC-FT	13	14	12	9.5	6.2	3.6	2.3	1,880	1,280	441	12	13

CALENDAR YEAR 1997 TOTAL 1,854.34 MEAN 5.08 MAXIMUM 327 MINIMUM 0.03 ACRE-FT 3,680

[1]Month in which data are provisional, subject to revision.

Table 9. Discharge measurements of selected springs, 1952–97

Spring name	U.S. Bureau of Indian Affairs site number	Rock Formations	Date of measurement	Discharge, in gallons per minute
Burro Spring	6M-31	Navajo Sandstone	12–15–89	0.4
			12–13–90	.4
			03–18–93	.3
			12–08–94	.2
			12–17–96	.4
			12–30–97	.2
Unnamed spring near Dennehotso	8A-224	Navajo Sandstone	10–06–54	[1]1
			06–27–84	[1].2
			11–17–87	.5
			03–26–92	.2
			10–22–93	14.4
			12–05–95	17
			12–19–96	15.7
			12–31–97	25.6
Moenkopi School Spring	3GS-77-6	Navajo Sandstone tongue in the Kayenta Formation	05–16–52	40
			04–22–87	16
			11–29–88	12.5
			02–21–91	[2]13.5
			04–07–93	[2]14.6
			12–07–94	[2]12.9
			12–04–95	[2]12.1
			12–16–96	[2]10
			12–17–97	[2]13.1
Pasture Canyon Spring	3A-5	Navajo Sandstone and alluvium	11–18–88	[3]211
			03–24–92	[3]233
			10–12–93	[3]211
			12–04–95	[4]38
			12–16–96	[4]38
			12–17–97	[4]40

[1]Estimated.

[2]Discharge measured at water-quality sampling site only and does not represent the total discharge from the Moenkopi School Spring system.

[3]Discharge measured in an irrigation ditch about 0.25 mile below water-quality sampling point and does not represent the total discharge from Pasture Canyon Spring.

[4]Discharge measured volumetrically from pipe at water-quality sampling point 20 feet below uppermost spring. Water was being diverted for irrigation upstream [illegible] previous points of measurement.

Water Chemistry

Water from Wells Completed in the N Aquifer

All but two wells (Red Lake PM1 and Dennehotso PM2) sampled in 1997 are completed in the confined part of the N aquifer (fig. 7). The primary types of water that occur in the N aquifer are calcium bicarbonate and sodium bicarbonate. Calcium bicarbonate water occurs in the northern and northwestern part of the Black Mesa area. Sodium bicarbonate water generally occurs elsewhere throughout the area. All but two (Red Lake PM1 and Kayenta PM2) of the 12 wells sampled contained a sodium bicarbonate water. Historically, water from Red Lake PM1 and Kayenta PM2 have been a calcium bicarbonate type (Littin, 1993). Although the Kayenta PM2 well penetrates the confined part of the N aquifer, the water is chemically similar to water from wells and springs associated with the unconfined areas of the N aquifer (fig. 8).

Figure 8. Relative compositions of ground water from the N aquifer in the Black Mesa area, 1997.

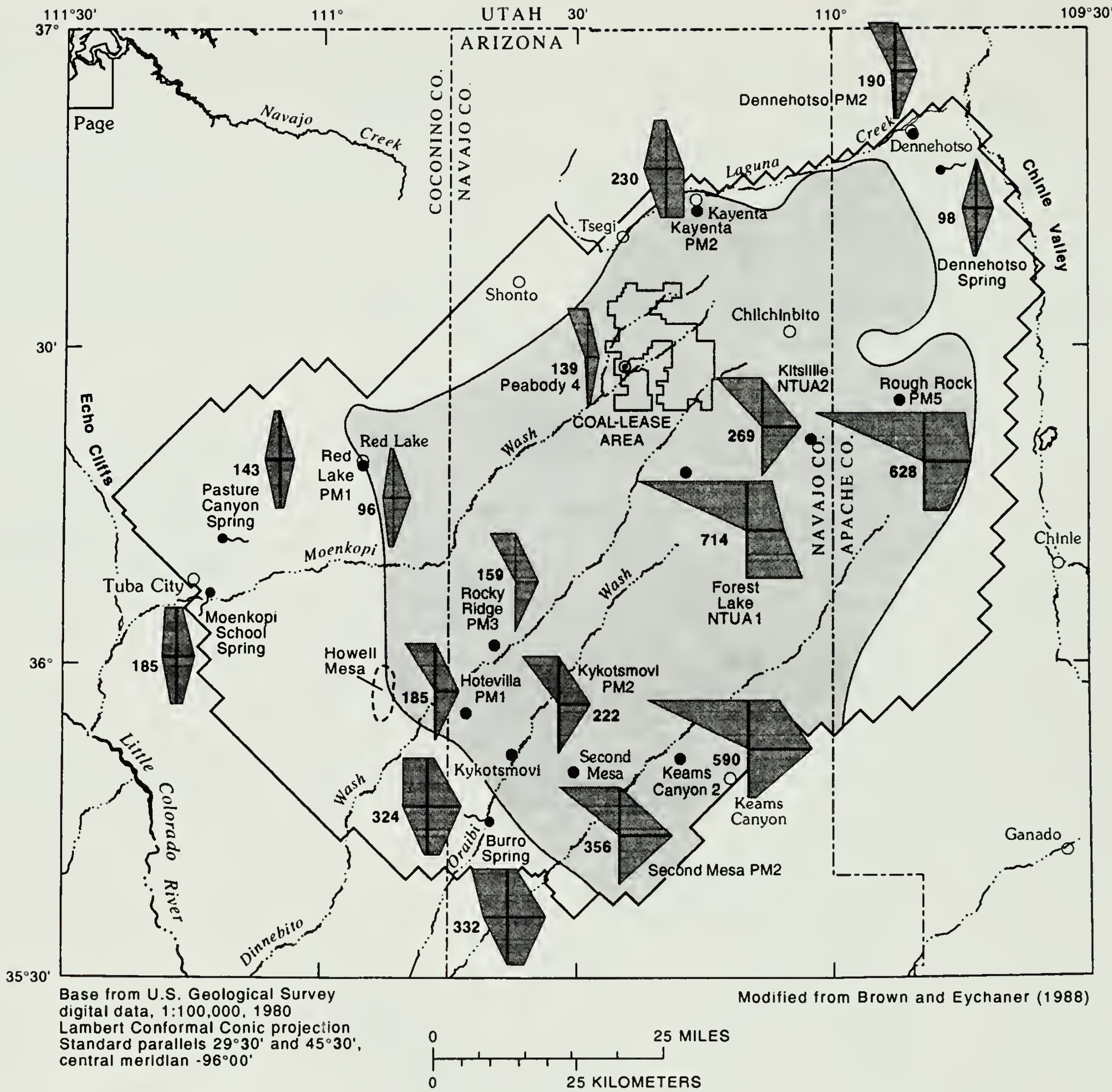

Figure 9. Water chemistry and distribution of dissolved solids in the N aquifer, 1997.

Dissolved-solids concentrations in water from wells completed in the N aquifer ranged from 96 mg/L at Red Lake PM1 to 714 mg/L at the Forest Lake NTUA1 well (fig. 9; tables 10 and 11). Long-term comparison of dissolved-solids concentrations in water collected from Keams Canyon 2 and Kayenta PM2[3] wells shows no significant change from 1982 to 1997 (fig. 10; table 11). Since 1991, an increase in concentrations of dissolved solids in water from the Forest Lake well NTUA 1 has been observed. During 1993 to 1996, dissolved-solids concentrations have averaged about 370 mg/L as compared to 250 mg/L prior to that time. In 1997, dissolved-solids concentrations at the Forest Lake well NTUA1 were measured at 714 mg/L. Regionally, long-term water-chemistry data for wells have remained stable. Locally, water-chemistry data for

[3]Well selection was based on sample frequency, length of record, consistency in sampling conditions, and representative spatiality.

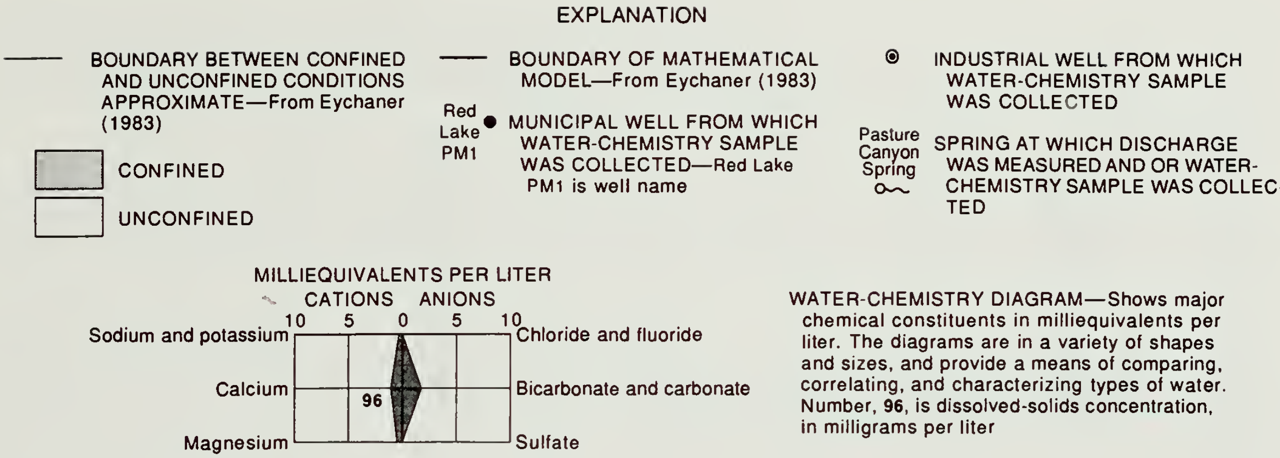

Figure 9. Continued.

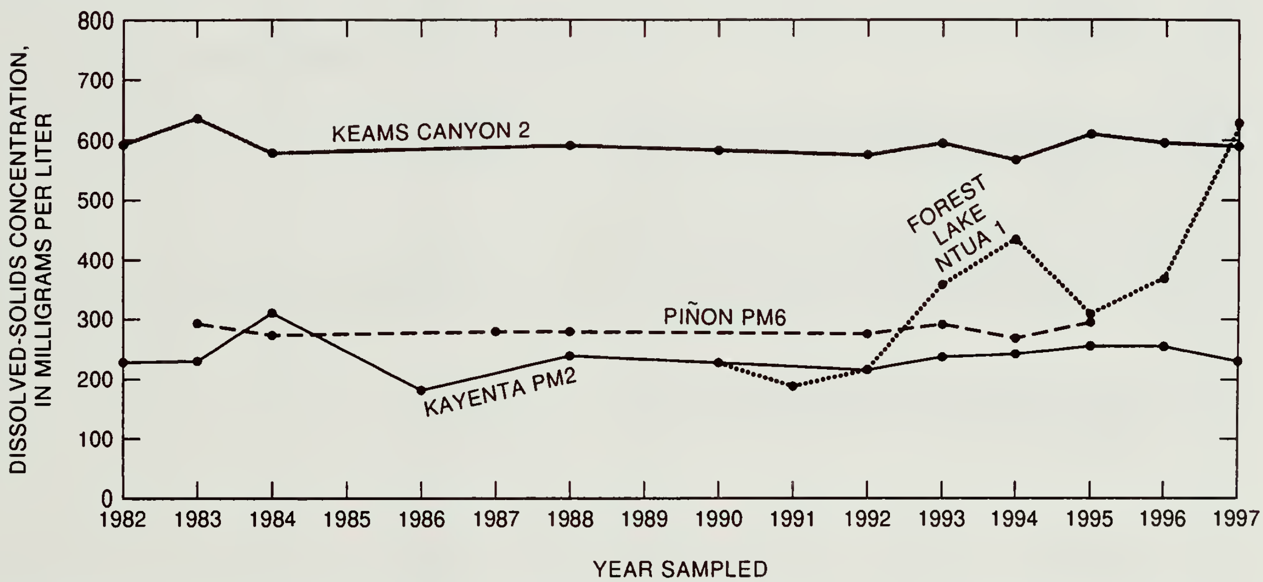

Figure 10. Dissolved-solids concentrations in water from wells Keams Canyon 2, Piñon PM6, Forest Lake NTUA 1, and Kayenta PM2, 1982–97.

some wells have shown marked changes in concentrations of major constituents.

Surface Water

Four springs were selected for water-chemistry analyses as part of the monitoring program during 1997 (figs. 7, 8, and 9; table 12). The springs, all of which discharge from the Navajo Sandstone, are Burro Spring near Kykotsmovi, an unnamed spring near Dennehotso, Moenkopi School Spring at Moenkopi, and Pasture Canyon Spring near Tuba City (figs. 7, 8, and 9; table 12).

Long-term water-chemistry data for these springs have remained stable. Over the last couple of years, dissolved-solids concentrations have decreased at all of the springs; however, over the last 10 years, concentrations have increased at two springs (table 13). Water from Burro Spring has been a sodium bicarbonate type and waters from an unnamed spring near Dennehotso, Moenkopi School Spring, and Pasture Canyon Spring have been calcium bicarbonate types. In 1997, dissolved-solids concentrations in water from the four springs ranged from 98 mg/L at the unnamed spring near Dennehotso to 332 mg/L at Burro Spring.

Table 10. Physical properties and chemical analyses of water from selected industrial and municipal wells completed in the confined part of the N aquifer, 1997

[°C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than]

Well name	U.S. Geological Survey identification number	Date of sample	Temperature (°C)	Specific conductance (µS/cm)	pH (units)	Alkalinity (mg/L as $CaCO_3$)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
Dennehotso PM2.......	365045109504001	12–09–97	13.7	318	8.9	126	1.5	0.10	8	1.9
Forest Lake NTUA1...	361737110180301	12–10–97	27.5	1,160	9.1	186	.28	.02	2.6	.32
Hotevilla PM1	355518110400301	12–16–97	24.5	307	9.6	140	1.1	.06	1.3	.03
Kayenta PM2..........	364344110151201	12–09–97	13	388	8	108	.98	.01	43	6.8
Keams Canyon 2	355023110182701	12–09–97	18.7	1,040	9.2	349	<.05	.09	.79	.15
Kitsillie NTUA 2	362043110030501	12–10–97	26.8	456	10	213	1.4	.05	.55	.01
Kykotsmovi PM2.....	355215110375001	12–12–97	21.8	374	10.1	166	1.2	.06	.48	.02
Peabody 4...........	362647110243501	12–10–97	32	210	9.4	84	1.0	.02	4.6	.04
Red Lake PM1	361933110565001	12–11–97	9	166	8.7	73	1.3	.01	19	5.0
Rocky Ridge PM3	360422110353501	12–11–97	22.5	255	9.8	113	1.3	.04	.66	.01
Rough Rock PM5.....	362418109514601	12–10–97	19.5	1,090	9.1	220	1.1	.01	3.3	.27
Second Mesa PM2....	354749110300101	12–11–97	19	615	9.9	282	<.05	.04	.45	.03

Well name	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Arsenic, dissolved (µg/L as As)	Boron, dissolved (µg/L as B)	Iron, dissolved (µg/L as Fe)	Dissolved solids, residue at 180°C (mg/L)
Dennehotso PM2	58	5.8	11	14	0.21	13	6	71	<10	190
Forest Lake NTUA 1 ..	236	1.3	78	250	1.5	17	1	481	38	714
Hotevilla PM1	65	.46	1.5	5.2	.14	25	3	23	<10	185
Kayenta PM2........	23	2.8	3.9	77	.14	18	2	23	<10	230
Keams Canyon 2	219	.69	96	33	1.4	13	42	632	<10	590
Kitsillie NTUA 2	98	.98	3.6	4.3	.28	28	4	55	<10	269
Kykotsmovi PM2.....	81	.98	3	8	.25	26	5	33	<10	222
Peabody 4...........	41	4.6	3.5	12	.17	24	3	19	<10	139
Red Lake PM1	5.8	.85	3.2	1.7	.16	11	<1	21	<10	96
Rocky Ridge PM3	55	.89	2.5	5	<.10	22	3	21	<10	159
Rough Rock PM5.....	230	9.4	130	110	1.8	13	48	419	<10	628
Second Mesa PM2....	134	.35	7.1	14	.33	21	15	98	<10	356

Table 11. Specific conductance and concentrations of selected chemical constituents in water from industrial and municipal wells completed in the confined part of the N aquifer, 1968–97

[μS/cm, microsiemens per centimeter at 25°C; °C, degrees Celsius; mg/L, milligrams per liter; --- no data]

Year	Specific conductance (μS/cm)	Dissolved solids, residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Forest Lake NTUA 1				
1982	470	---	11	67
1990	375	226	8.2	38
1991	321	183	10	24
1993	693	352	35	88
1994	744	430	56	100
1995	470	274	13	60
Do.	1,030	626	86	160
Do.	488	316	16	71
1996	684	368	44	79
1997	1,160	714	78	250
Hotevilla PM1				
1990	290	192	1.6	5
1991	304	208	.7	5.4
1993	305	180	1.2	5.5
1994	307	166	1.4	4.8
1995	282	196	1.4	3.7
1996	328	186	1.3	5.3
1997	307	185	1.5	5.2
Kayenta PM2				
1982	360	228	4.5	58
1983	375	230	---	60
1984	365	209	4.2	51
1986	300	181	8.2	30
1988	358	235	3.8	74
1992	383	210	5.6	78
1993	374	232	3.7	78
1994	379	236	4.2	77
1995	371	250	4.2	72
1996	370	238	3.8	76
1997	388	230	3.9	77
Keams Canyon 2				
1982	1,010	592	94	35
1983	1,120	636	120	42
1984	1,040	578	96	36
1988	1,040	591	97	34
1990	1,030	600	94	34
1992	1,008	570	93	36
1993	1,040	590	92	36
1994	991	562	88	32
1995	1,010	606	99	32
1996	1,030	596	96	34
1997	1,040	590	96	33
Kykotsmovi PM2				
1988	368	212	3.2	8.6
1990	355	255	3.2	9
1991	372	203	4.4	7.9
Kykotsmovi PM2—Continued				
1993	363	212	3.3	8.4
1994	372	212	3.6	8.5
1995	368	224	3.1	6.2
1996	365	224	3.3	8.5
1997	374	222	3.0	8.0
Peabody 4				
1980	230	139	4.3	13
1986	205	---	4.2	12
1987	194	135	5	13
1992	224	125	4.3	12
1993	214	124	3	12
1996	214	140	3.8	12
1997	210	139	3.5	12
Dennehotso PM2				
1992	226	131	9.8	19
1997	318	190	11	14
Kitsillie NTUA 2[1]				
1997	456	269	3.6	4.3
Red Lake PM1				
1992	164	87	2.6	1.9
1997	166	96	3.2	1.7
Rocky Ridge PM3				
1982	255	---	1.4	
1990	222	126	1.5	6
1993	254	146	1.3	5.5
1994	247	152	1.4	5.5
1995	242	166	1.3	4
1996	256	158	2.0	5.8
1997	255	159	2.5	5.0
Rough Rock PM5				
1983	1,090	628	130	110
1984	1,090	613	130	99
1986	1,010	633	140	120
1988	1,120	624	130	109
1991	1,060	574	190	110
1993	1,040	614	130	110
1994	1,180	626	130	110
1995	1,110	648	140	110
1996	1,100	634	130	110
1997	1,090	628	130	110
Second Mesa PM2				
1990	590	364	6.5	16
1991	613	292	10	15
1993	630	350	7.5	15
1994	614	342	7.6	15
1997	615	356	7.1	14

[1]New well.

Table 12. Physical properties and chemical analyses of water from selected springs that discharge from the N aquifer, 1997

[°C, degree Celsius; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; µg/L, micrograms per liter; ---, no data]

Spring name	Bureau of Indian Affairs field number	U.S. Geological Survey identification number	Rock formation	Date of sample	Temperature (°C)	Specific conductance (µS/cm)	pH (units)
Burro Spring	6M-31	354156110413701	Navajo Sandstone	12–30–97	14.0	574	7.6
Unnamed spring near Dennehotso	8A-224	364656109425400	Navajo Sandstone	12–30–97	8.9	191	---
Moenkopi School Spring	3GS-77-6	360632111131101	Navajo Sandstone tongue in the Kayenta Formation	12–17–97	17.5	318	7.4
Pasture Canyon Spring	3A-5	361021111115901	Navajo Sandstone	12–17–97	15.0	232	7.4

Spring name	Alkalinity (mg/L as $CaCO_3$)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
Burro Spring	180	0.33	0.01	120	---	44	3.0
Unnamed spring near Dennehotso	---	1.6	.03	81	---	26	3.8
Moenkopi School Spring	97	2.4	.01	97	---	28	6.3
Pasture Canyon Spring	78	4.5	.02	89	---	29	4.4

Spring name	Sodium, dissolved (mg/L as Na)	Sodium adsorption ratio	Percent sodium	Sodium plus postassium, dissolved (mg/L as Na+K)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)
Burro Spring	77	3	58	78	0.5	26
Unnamed spring near Dennehotso	3.9	.2	10	4.8	.9	2.4
Moenkopi School Spring	25	1	36	26	1.3	18
Pasture Canyon Spring	11	.5	22	12	1.4	5.3

Spring name	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Arsenic, dissolved (µg/L as As)	Boron, dissolved (µg/L as B)	Iron, dissolved (µg/L as Fe)	Dissolved solids, residue at 180°C (mg/L)
Burro Spring	75	0.44	13	1	76	1	332
Unnamed spring near Dennehotso	6.1	.16	12	3	20	2	98
Moenkopi School Spring	24	.13	15	3	41	<10	185
Pasture Canyon Spring	17	.11	11	2	30	<10	143

Table 13. Specific conductance and concentrations of selected chemical constituents in water from springs that discharge from the N aquifer, 1948–97

[µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; °C, degrees Celsius; ---, no data]

Spring name	Year	Specific conductance (µS/cm)	Dissolved solids, residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Burro Spring......	1989	485	308	22	59
	1990	546	347	23	65
	1993	595	368	30	85
	1994	601	368	26	80
	1996	525	324	23	62
	1997	574	332	26	75
Unnamed spring near Dennehotso......	1984	195	112	2.8	7.1
	1987	178	108	3.4	7.5
	1992	178	108	3.6	7.3
	1993	184	100	3.2	8
	1995	184	124	2.6	5.7
	1996	189	112	2.8	8.2
	1997	191	98	2.4	6.1
Moenkopi School Spring	1952	222	----	6	----
	1987	270	161	12	19
	1988	270	155	12	19
	1991	297	157	14	20
	1993	313	204	17	27
	1994	305	182	17	23
	1995	314	206	18	22
	1996	332	196	19	26
	1997	318	185	18	24
Pasture Canyon Spring....	1948	199	123	5	13
	1982	240	----	5.1	18
	1986	257	----	5.4	19
	1988	232	146	5.3	18
	1992	235	168	7.1	17
	1993	242	134	5.3	17
	1995	235	152	4.8	14
	1996	238	130	4.7	15
	1997	232	143	5.3	17

SUMMARY

The N aquifer is a major source of water for industrial and municipal uses in the Black Mesa area, and water occurs under confined and unconfined conditions. From 1996 to 1997, combined ground-water withdrawals increased by less than 1 percent to about 7,090 acre-ft; pumpage from the confined part of the aquifer increased by about 2 percent to 5,510 acre-ft and pumpage from the unconfined part of the aquifer decreased by about 4 percent to 1,580 acre-ft.

Water-level declines in the confined area during 1997 were recorded in 5 of 12 wells, and the median change was a rise of about 0.2 ft as opposed to a decline of 2.8 ft for 1996. Water-level declines in the unconfined area were recorded in 7 of 15 wells, and the median change was 0.0 ft in 1997 as opposed to a decline of 0.5 ft in 1996.

Natural discharge from the N aquifer is mainly surface flow along Moenkopi Wash and Laguna Creek and discharge from springs near the boundaries of the aquifer. Measured low flow ranged from 1.6 to 2.0 ft^3/s along Moenkopi Wash, 2.3 to 4.2 ft^3/s at Laguna Creek, 0.44 to 0.48 ft^3/s at Dinnebito, and 0.15 to 0.26 ft^3/s at the Polacca gage in 1997. The Dinnebito and Polacca gages were recently added to the network to monitor spring discharge along the southern boundary of Black Mesa. Spring discharge increased by 3.1 gal/min at Moenkopi School Spring, 9.9 gal/min at the unnamed spring near Dennehotso, and 2 gal/min at Pasture Canyon, and decreased slightly at Burro Spring.

Calcium bicarbonate water and sodium bicarbonate water are the primary types of water that occur in the N aquifer. The calcium bicarbonate type water occurs in the northern and northwestern part of the Black Mesa area. The sodium bicarbonate type water generally occurs elsewhere throughout the area. All but two (Red Lake PM1 and Kayenta PM2) of the 12 wells sampled in 1997 contained a sodium bicarbonate type water. Historically, water from Red Lake PM1 and Kayenta PM2 has been a calcium bicarbonate type (Littin, 1993). Dissolved-solids concentrations ranged from 96 to 714 mg/L in 1997.

Recent increases in concentrations of dissolved solids in water from Forest Lake well NTUA 1 have been observed. Regionally, long-term water-chemistry data for wells and springs have remained stable. Locally, water-chemistry data for some wells have shown marked increases in concentrations of major constituents.

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